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ABSTRACT

The majority of research on mathematics practice in everyday situations within cultures has investigated the use of arithmetic and geometry concepts and processes. To extend this research to a situation using measurement ideas, this paper investigates the mathematics practice of a group of carpet layers in an effort to detail how ordinary people "actively give meaning to, and fashion, processes of problem solving in the midst of ongoing activities in relevant Settings" (Lave, 1988). Data were collected by observing and informally questioning the employees of a carpet laying business. Four areas of mathematics concepts used by the estimators and/or installers were observed: measurement, computational algorithms, geometry, and ratio and proportion. Two general observations were made: (1) the estimators and installers were not concerned with square footage of a room but with the square feet of carpet needed in the room, and (2) all problems in carpet laying are optimization problems. (MKR)

The Mathematics Practice of Carpet Layers: A Closer Look at Problem Solving in Context

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Introduction

Researchers in the last two decades have shown great interest in examining the mathematics practice of persons in: (a) distinct cultures (e.g., Brenner, 1985; Gerdes, 1986; Saxe, 1981, 1988) and (b) everyday situations within cultures (e.g., de la Rocha, 1986; Lave, 1977; Millroy, 1992). This study builds upon research in both of these areas, but particularly on research considering mathematics practice in everyday situations.

The majority of research on mathematics practice in everyday situations within cultures has investigated the use of arithmetic and geometry concepts and processes. To extend this research to a situation using measurement ideas, I investigated the mathematics practice of a group of carpet layers in an effort to detail how ordinary people "actively give meaning to, and fashion, processes of problem solving in the midst of ongoing activities in relevant settings" (Lave, 1988, p. 63). I chose the everyday situation of carpet laying because measurement is a central concept and measuring is a central process in carpet laying work. Measurement as a concept is the idea that characteristics of objects can be quantified (e.g., the space inside a region can be quantified as the number of square units—area) whereas measuring as a process is the action taken to quantify those characteristics.

Measurement is different in some fundamental ways from arithmetic and geometry. For example, measurement units are determined more clearly by cultural convention than are aspects of arithmetic and geometry practice. Gay and Cole (1967) found, for example, that measures of volume, in units that were socially established, were used by the Kpelle in Liberia in situations where the amount of a given material was important. Buying and selling rice, the staple food of the Kpelle, were two such situations.

The local trade uses what is called a *sâmo-ko*, "salmon cup," for dealing rice. It is the large size tin can (U.S. #1) in which salmon is normally packed. . . . The cup the trader uses to buy rice has the bottom rounded out by long and careful pounding, but the cup he uses to *sell* rice does not have the rounded bottom. This is the source of his profit. (p. 64)

Measurement is also a key part of the school mathematics curriculum. In fact, the *Curriculum and Evaluation Standards for School Mathematics* (National Council of Teachers of Mathematics (NCTM), 1989) stated that "measurement is of central importance to the curriculum because of its power to help children see that mathematics is useful in everyday life and to help them develop many mathematical concepts and skills" (NCTM, 1989, p. 51). However, measurement knowledge in school is often limited to memorizing formulas (e.g., $P = 2(l + w)$ and $A = l \bullet w$) and learning measurement skills such as how to use a ruler, whereas measurement knowledge in the workplace is primarily comprised of concepts and processes central to measuring, such as area expressed as square units, estimation, spatial visualization, minimizing error, and efficiency.

Structure and Aim of the Study

Various conceptual, theoretical, and methodological frameworks guided the conceptualization, design, and conduct of this study—a cultural framework of ethnomathematics, an epistemological framework of constructivism, a cognitive framework of activity theory, and a methodological framework of ethnography. I will elaborate on the cognitive framework here and discuss later how this framework was used in collecting and interpreting the data.

Cognitive Framework

To focus this study in exploring cognition in culture, I used the theory of activity as a guiding framework. The theory of activity has its origins in the work of the Soviet psychologist Vygotsky and has been developed over the years by his successors, especially Leont'ev. Activity theory is a "theoretical framework which affords the prospect of an integrated account of mind-in-action" (Scribner, 1984a, p. 2). This theory emphasizes that humans act within sociocultural contexts that need to be considered when studying cognition.

Instead of studying psychological entities such as skills, concepts, information-processing units, reflexes, or mental functions, the theory of activity focuses on the unit of activity. One of the key characteristics of an activity is that it "is not determined or even strongly circumscribed by the physical or perceptual context in which humans function. Rather, it is a sociocultural interpretation or creation that is imposed on the context by the participant(s)" (Wertsch, 1985, p. 203).

Aim of the Study

The general aim of this study was to develop a better understanding of mathematics practice in everyday situations. To this end, I focused my attention on one particular type of mathematics practice—mathematics practice in carpet laying. More specifically, my aim was to identify the mathematics concepts and processes used in the context of carpet laying and examine what this data can add to the study of everyday mathematics. My motivation for this study and future research is to develop a model for connecting in-school and out-of-school mathematics practice.

Data Sources and Methods

In order to achieve these two aims, I spent an average of four hours a day, five days a week for seven weeks during June, July, and August 1991 observing and informally questioning the employees of a carpet laying business, Miller's Floor Coverings (a pseudonym), in the midwestern region of the United States. I used four methods of data collection in my fieldwork: participant observation, ethnographic interviewing, artifact examination, and researcher introspection.

Data Collection

Although I did not participate in the actual laying of floor coverings, I participated in the discussion and decision making accompanying any estimation or installation job. My participation was not, however, that of contributing ideas or making suggestions. Rather, I asked questions to clarify what I heard and participated in casual conversation. I also participated by going to the estimation and installation sites, holding tape measures, helping chalk lines, and carrying equipment and materials.

I observed Miller's employees through the entire floor covering process for a variety of situations: (a) residential and commercial settings, (b) one-room jobs up through entire buildings, and (c) carpet, tile, hardwood, and base installations. I chose to observe work tasks completed by both estimators and installers. I observed the estimators taking field measurements, making sketches, and deciding on best estimates. I observed the installers interpreting the estimator's sketches and estimates, measuring, deciding on best installations, and installing floor coverings.

Criteria for selecting work tasks to be observed and analyzed included that the tasks: (a) involved person-world transactions, (b) were essential to, if not constitutive of, job performance, and (c) involved observable modes of solution, as well as solutions. These criteria have been used successfully in other studies to select candidate tasks for cognitive analysis (e.g., Scribner 1984b). I examined (and made copies of) all sketches and calculations made by estimators and installers, as well as blueprints used for commercial floor covering jobs, for information that might aid me in my research. Along with creating an expanded account of my field notes, which included observations, interviews, and artifact notes, I also recorded my reflections, feelings, reactions, insights, and emerging interpretations daily in a journal.

Data Analysis

The data were analyzed using the theory of activity (Eckensberger & Meacham, 1984; Leont'ev, 1981; Wertsch, 1985) as a framework. Leont'ev (1981) has specified several distinct but interrelated levels of analysis present in the theory of activity, with a specific type of unit associated with each level. The three levels are *activity, goal-directed action*, and *operation*. Among the activities in which humans engage are several that have been mentioned by Vygotsky's students (e.g., El'konin, 1972): play, instruction, and work. I chose the activities that occur in the workplace to focus on for reasons of both significance and strategy. Work is obviously significant; it is basic to human life in all societies and all cultures and occupies a great part of an adult's time.

When I considered examining mathematics practice in everyday situations, the strategies involved in such research also pointed in the direction of the workplace. Occupations such as carpet estimating and installing are "highly structured and involve tasks whose goals are predetermined and explicit" (Scribner, 1984a, p. 3). Following Scribner's example, I used *occupations*, *work tasks*, and *conditions* to represent the three levels of analysis—*activities*, *goal-directed actions*, and *operations*.

The two *occupations* for which I collected data were estimator and installer. The *work tasks* in the estimator's job that interested me include: (a) taking field measurements, (b) making sketches, and (c) deciding on best estimates. Those in the occupation of installer include: (a) interpreting the estimator's sketch and estimate, (b) measuring, (c) deciding on best installations, and (d) installing.

Like most situations in everyday life, the processes of estimating and installing floor coverings have many constraints that must be taken into consideration during these processes. These constraints are the *conditions* that I focused on for this study. Constraints I observed include that: (a) floor covering materials come in specified sizes (e.g., most carpet is 12' wide, base (vinyl piece glued around the perimeter of a room) is 4' long, most tile is 1' by 1'), (b) carpet pieces are rectangular, (c) carpet in a room (and often throughout a building) must have the nap (the dense, fuzzy surface on carpet formed by fibers from the underlying material) running in the same direction, (d) consideration of seam placement is very important because of traffic patterns and the type of carpet being installed, (e) some carpets have patterns that must match at the seams, (f) tile and hardwood pieces must be laid to be lengthwise and widthwise symmetrical about the center of the room, and (g) fill pieces for both tile and base must be six inches wide or more to stay in place.

I analyzed the field data through a process of inductive data analysis using two subprocesses that Lincoln and Guba (1985) have called unitizing and categorizing. The work tasks that I observed were chosen through purposive sampling and changed as the study design emerged. Several times per week I reflected upon the estimation and installation work tasks I had observed thus far and made sampling decisions to: (a) observe certain work tasks again, (b) ask specific questions of certain respondents, (c) observe unfamiliar work tasks, and (d) discontinue the observation of work tasks for which I felt I had enough data.

Mathematical Concepts and Processes: Evidence of Problem Solving

I observed four areas of mathematical concepts used by the estimators and/or the installers: measurement, computational algorithms, geometry, and ratio and proportion. The estimators and installers also made use of several mathematical processes: measuring and problem solving. This paper will focus in detail on the process of problem solving and the range of strategies used by the carpet layers.

The mathematical process of problem solving is used by floor covering workers every day as they make decisions about estimations and installations. However, the problem solving that occurred in this context is slightly different from how problem solving is typically defined. Problem solving is commonly thought of as the process of coordinating previous experiences, knowledge, and intuition in an effort to determine an outcome of a situation for which a procedure for determining the outcome is not known (Charles, Lester & O'Daffer, 1987). Problem solving in the floor covering context deviated from this definition in that procedures for determining outcomes were usually known. However, unfamiliar constraints (e.g., a post in the middle of the room) and irregular shapes of rooms forced floor covering workers to coordinate their previous experiences, knowledge, and intuition to determine outcomes of situations they faced.

The problems that estimators and installers encountered required various degrees of problem-solving expertise. As the shape of the space being measured (or in which floor covering material was being installed) moved away from a basic rectangular shape, the level of expertise required increased. To solve problems occurring on the job, I observed Miller's Floor Coverings employees use four categories of problem-solving strategies: using a tool, using a picture, checking the possibilities, and using an algorithm.

Using a tool. I observed both estimators and installers use tools that aided them in the problem-solving process of deciding an estimation or installation job. In particular, both estimators and installers used tape measures. Estimators used a tape measure to take the measurements they need to make a decision about how the carpet should be laid, where the seams should be, and how much carpet is needed. Installers likewise measured to check the estimator's measurements and made adjustments if necessary.

A measurement trundle wheel and a drafting ruler were tools that were used in the preparation of commercial bids. Gene, an estimator, used a trundle wheel with blueprints to measure the perimeter of rooms in which base would be installed. The trundle wheel had the scale of 1/8 inch = 1 foot and even though measurements taken on a blueprint drawn in a scale other than 1/8 inch = 1 foot had to be converted, the trundle wheel was useful because it could measure the perimeter of any shape quickly and with acceptable accuracy. Because of the wheel feature the trundle wheel could be maneuvered easily around corners and juts on the blueprints to accurately assess the perimeter of the region.

Gene also used a drafting ruler to measure the maximum length and width of each room being carpeted. A drafting ruler has six measuring sides, each with two scales. Gene told me that most of the blueprints he works with are drawn in one of two scales: "Most of the blueprints come in 1/4 inch = 1 foot or 1/8 inch = 1 foot scales so I mainly use those two scales on the ruler, but if I need the others I have them." The drafting ruler is a useful tool in measuring and converting the blueprint measurements to feet. These measurements can then be used with other factors (e.g., cost efficiency, seam placement, pattern of carpet, type of carpet) to determine how the carpet should be laid and how much carpet is needed for the job.

Using a picture. In all the floor covering situations I observed, pictures were used to help visualize the situation and function as a problem-solving tool. These pictures were either blueprints or hand-drawn sketches. I observed Phil, an installer, use a drawing to solve the problem of matching the pattern in a carpet in a commercial carpet installation. This installation was in a university dormitory and involved several intersecting hallways on a number of floors and carpet with a pattern that repeated every three inches. The hallways were very long (e.g., one was approximately 125' long) and since the carpet was sent from the supplier in rolls of varying lengths, all less than 100', some butt seams (two carpet pieces seamed end-to-end) were necessary (see Figure 1).

Phil, who earlier in the summer had been Jack's (another installer) regular helper, was now two weeks into heading an installation crew with Matt as his helper. Because of his newly acquired status and his desire to prove himself as an installer, Phil was very thorough about sizing up a situation before he started the installation. In this case he saw that it was important to consider carefully where to begin the installation and in what order to install the remaining carpet pieces given that the pattern must match at all the hallway intersections. The sketch had carpet pieces labeled A-F but these letters were simply to label the pieces, not to suggest the order of installation.

All of the hallways were 4' 4" wide and, while pieces B, D, and F were 4' 6" wide and quite long, pieces A, C, and E were 12' wide and 4' 8" long. The carpet nap would be running in the direction of the length of piece B. Phil talked aloud and tried different ways of numbering the six pieces of carpet on the sketch, indicating the order of installation and discussing the situation with Matt. Every once in awhile he would make comments directed toward me, explaining why a certain choice was or was not feasible. Finally, Phil decided that they would install the carpet piece labeled F first and then D, matching the pattern at the butt seam. The third piece to be installed would be E and this piece must match the pattern in F at the side seam. This would require some careful installation since with the hallway 4' 4" wide, the carpet 4' 8" and the pattern repeating every 3" there would be very little room for maneuvering.

Phil told me he would then install piece B, matching the pattern in E at the side seam. Piece C would then be installed. This would be the most difficult carpet piece to install since this piece must match the pattern in B and D. Phil remarked that he might have to work to shift one of the pieces (B or D) to match at the side seam. Piece A would be installed last, cut into two pieces matching B at the side seams.

Phil used the drawing of the hallways to visualize the installation and seam placements. By ordering the pieces and thinking about how installing the pieces in this order would affect the ease of matching the pattern he was able to choose an appropriate order for installation.

Checking the possibilities. I observed a number of situations where estimators or installers checked possible solutions in solving a problem. I grouped these situations into four categories according to the activity involved: weighing cost efficiency against seam placement, checking the amount of carpet against the area to be carpeted, deciding on roll cuts, and deciding on tile and hardwood work.

The following example illustrates the problem-solving process of weighing cost efficiency against seam placement. One carpet estimate situation I observed involved a pentagonal-shaped room in a basement. I accompanied Dean, an estimator, as he took field measurements and figured the estimate. The maximum length of the room was 26' 2" and the maximum width was 18' 9" (see Figure 2). Dean decided this room would have to be treated as a rectangle and figured how much carpet would be needed by checking two possibilities: (a) running the carpet nap in the direction of the maximum length, and (b) turning the carpet 90° so that the carpet nap ran in the direction of the maximum width.

In the first case, two pieces of carpet each 12' by 26' 4" would need to be ordered. After one piece of carpet 12' by 26' 4" was installed, a piece of carpet 6' 11" by 26' 4" would be needed for the remaining area. Since only one piece 6' 11" wide could be cut from 12' wide carpet, multiple fill pieces could not be used in this situation. Thus, a second piece of carpet 12' by 26' 4" would be needed for a total of 70.22 square yards. The seam for this case is shown by a thin line in Figure 2.

Turning the carpet 90° would require two pieces 12' by 18' 11" and a piece 12' by 4' 9" for fill. The 12' by 4' 9" piece would be cut into four pieces, each 2' 4" by 4' 9". The seams for this case are shown by thick lines in Figure 2. The total amount of carpet needed for this case would be 56.78 square yards. This second case has more seams than the first, but the fill piece seams are against the back wall, out of the way of the normal traffic pattern. Thus, these seams do not present a large problem. In both cases there would be a seam in the middle of the room. The carpet in the first case would cost at least $200 more than the carpet in the second case. Dean weighed the cost efficiency against the seam placement and decided that the carpet should be installed as described in the second case.

Using an algorithm. In other places (e.g., Masingila, 1994), I have discussed the computational algorithms that are used by estimators in measuring situations to find the quantity of materials needed for an installation job. For example, the estimators used algorithms to estimate the (a) amount of carpet, (b) amount of tile, (c) amount of hardwood, and (d) amount of base, and to convert square feet to square yards. These algorithms were used, not in a problem-solving manner, but rather to obtain a number representing a quantity of material. Put another way, the estimators did not use the algorithms to help them make decisions; the decisions had already been made and the task was simply to find how much of each material was needed.

Unlike the use of algorithms in the foregoing sorts of estimating situations, I observed installers use an algorithm in situations where it helped the installer make a decision concerning an installation job. The algorithm that I observed installers use in the process of solving these problems involved determining how tile should be laid in order that it be lengthwise and widthwise symmetrical about the center of the room.

The algorithm involved several steps. The first step was to measure the maximum length and width of the room. These measurements were then divided by two and expressed in feet and inches. The center of the room was found by using these half-measures to measure out from the respective walls and chalk lines representing the length- and width-bisectors. The intersection of these bisectors was the center of the room.

However, if only these lines were used as a guide for laying the tile, a problem might arise: Besides being lengthwise and widthwise symmetrical about the center of the room, tile must also be laid such that the fill pieces are greater than or equal to six inches (in order to stay in place). Thus, lining up full tile pieces against the bisectors that establish the center of the room and extending the tile to the wall may result in fill pieces with width less than six inches filling the gap between the full tiles and the wall.

What was done to avoid this problem was to consider the maximum length and width measurements one at a time, after they had been divided by two. Expressing these measurements in feet and inches provided the installer with necessary information: The number of feet represented the number of full tiles from the center of the room to the wall and the number of inches represented the width of the fill piece of tile to bridge the gap between the full tiles and the wall (tiles are 1' by 1'). If the number of inches was less than six, the tiles were shifted six inches (half of a tile). In other words, instead of a full tile edge touching the length-bisector (or width-bisector), the tile was placed so that the bisector ran through the center of the tile (see Figure 3). This shifted the tiles so that the fill tile on each of the two sides split by the length-bisector (or width-bisector) was greater than or equal to six inches, thereby helping the fill tile to stay glued down.

Sometimes both the length and width tile placements needed to be shifted, sometimes only one, and sometimes the measurements worked out so that no tile shift was needed. Along with considering the previously mentioned constraints, other complicating factors often arose. A discussion of a situation where this algorithm was used will help to illustrate its use.

The first tile installation I observed was at a commercial job site where tile was being installed in a kitchen. The kitchen had cabinets along a large portion of the walls but also had spaces between cabinets that had to be tiled (see Figure 4). Steve was the installer figuring this job and he first measured the maximum length of the room and found it to be 18' 8". Taking half of this gave 9' 4". Since four inches is too short for the fill pieces, the tile had to be shifted six inches—making the fill on each end 10". Thus, a measurement of 9' 4" from one of the end walls toward the center of the room would reach the center of a full tile (after the tile was installed) instead of the edge of one.

Steve next measured from cabinet-front to cabinet-front across the width of the room and found that measurement to be 7' 8 1/2". Half of this is 3' 10 1/4" so no shifting was necessary.

However, the tile across the width of the room would extend, at some parts, all the way to the wall since cabinets did not cover all the wall space. In considering the fill tile for these cabinet-free spaces, Steve measured from the front of the cabinets back to the wall and found this measurement to be 1' 7". Thus, from the width-bisector to a cabinet-free wall the measurement was 5' 5 1/4". Since the fill tile for these spaces was less than six inches, Steve considered whether he should shift the tiles six inches across the width of the room. After some calculations and muttering to himself, Steve decided not to shift the tile because that would throw off the fill pieces for the region from cabinet-front to cabinet-front. Besides, since most of the cabinet-free space along the walls would be later filled by appliances, Steve noted that it was more important to have the necessary fill for the space along the cabinets.

This example illustrates how installers used this algorithm to aid them in solving the problem of installing tile. The algorithm did not produce a number that solves the problem, but rather it was a mechanism to be used for making decisions about how the problem should be solved.

Discussion

There are two general observations I would like to make about the problem-solving activity of the estimators and installers. One is that they have a different way of thinking about area than other people might. The estimators and installers are not concerned with answering the question: What is the square footage of a room? Rather, they want to answer the question: How many square feet of carpet are needed in this room? Attempting to answer the second question forces the carpet layers to deal with a whole host of constraints that one does not need to consider when answering the first question.

The second observation is that, in the carpet laying context, all problems are optimization problems. The nature of these problems allows them to have multiple solutions including trade off solutions. If we think of a problem situation and all that it involves as the problem space, then we can observe that the estimators and installers described here have developed experienced-based knowledge about the solution space within the problem space.

My reason for using activity theory as a conceptual framework for this research is that it allows one to address the relationship between knowing and doing by proposing that the "starting point and primary unit of analysis should be culturally organized human activities" (Scribner, 1985, p. 199). By focusing on the activities of floor covering estimators and installers, examining the tasks involved in their work, and the conditions that they encounter and with which they must deal in each task provided me the opportunity to see these persons using their knowledge to interact with their environment through activities of locating and measuring; this systems approach is at the core of activity theory. To understand mathematics practice in the everyday context of carpet laying, I needed to analyze the activities and the actions in which they are embedded; activity theory provided the framework for this analysis.

The research discussed here adds to other research on the mathematics concepts and processes used in everyday situations by extending that research to a measurement context. Other research has examined the use of (a) arithmetic (e.g., de la Rocha, 1986; Murtaugh, 1985; Scribner, 1984c) (b) geometry (e.g., Millroy, 1992), and (c) rational number concepts (e.g., Carraher, 1986). This research on mathematics practice in the floor covering context provides some insight into what is involved in measurement practice in everyday situations.

Furthermore, this research combines some aspects of different types of research in this area. Some researchers have focused on situations in which people develop strategies that become fairly routinized (e.g., Lave, 1988; Scribner, 1984b, 1984c, 1984d) while others have examined situations where problem solving is adaptive (e.g., de la Rocha, 1986; Saxe, 1988). The mathematics practice of the floor covering workers involves features of both of these aspects. Many of the procedures and algorithms used in this context have become somewhat routine for the carpet layers. For example, the installers know how to follow the algorithm described previously for deciding how to lay tile. However, the numerous and varied constraints that occur at different job sites force the carpet layers to be adaptive in their problem solving. At one location Steve was faced with carpeting a room with a rectangular-prism post from floor to ceiling in approximately the center of the room. He needed to install the carpet around the post and minimize the seams. Thus, this research builds on aspects from two strains of research on mathematics practice in everyday situations.

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Carpet Installation Involving Intersecting Hallways

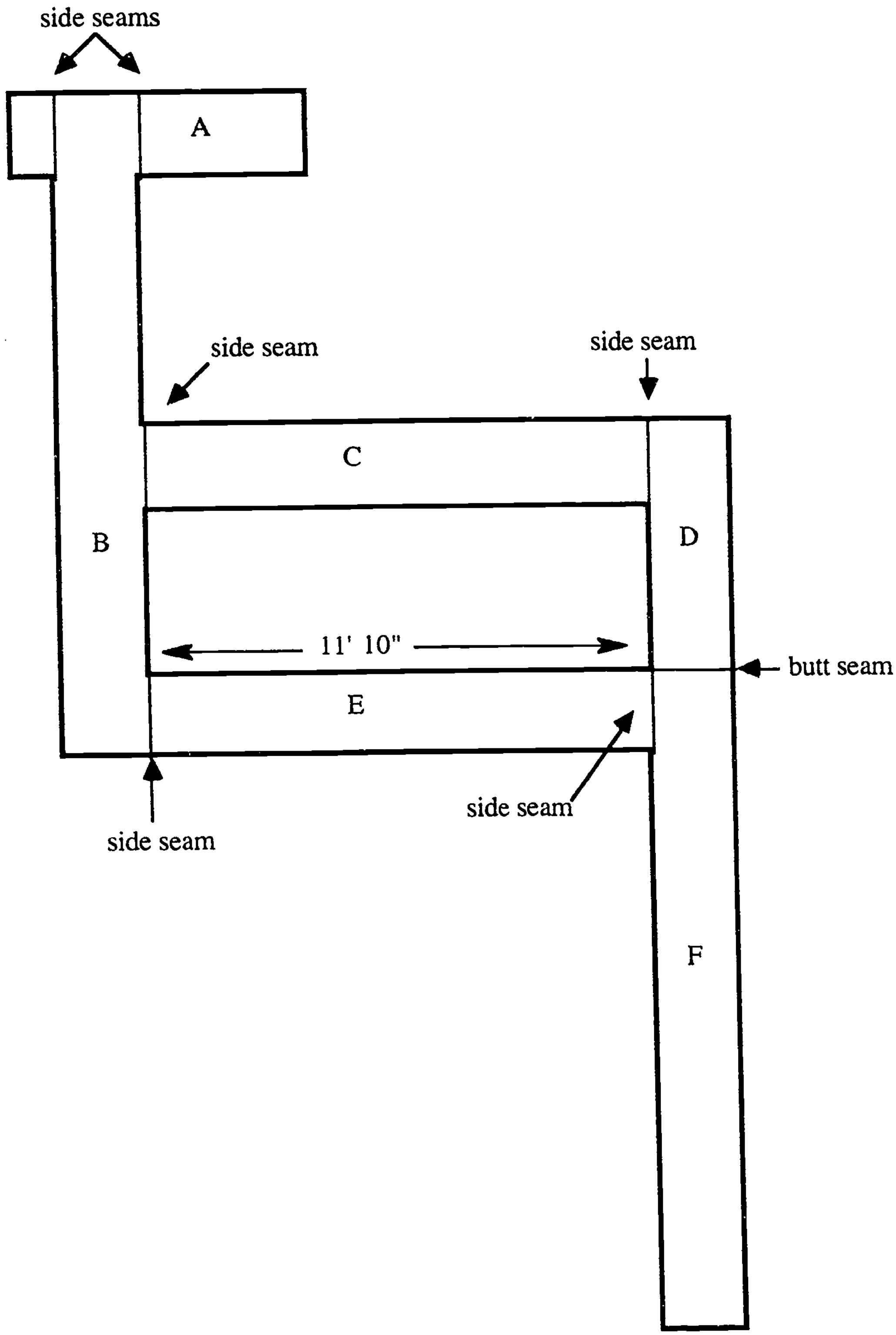

Figure 1

Pentagonal Basement Room

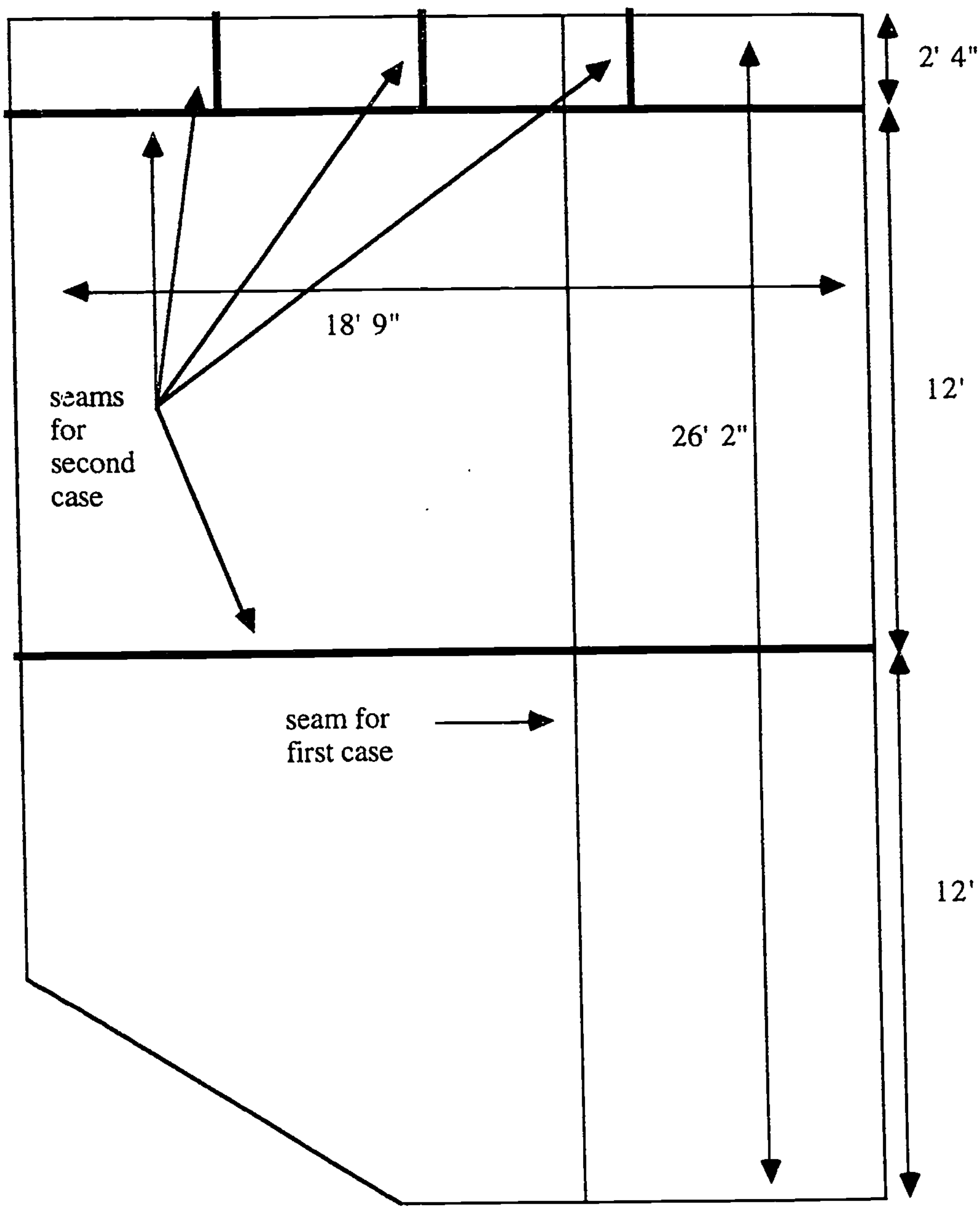

Figure 2

Shifting Tiles Six Inches

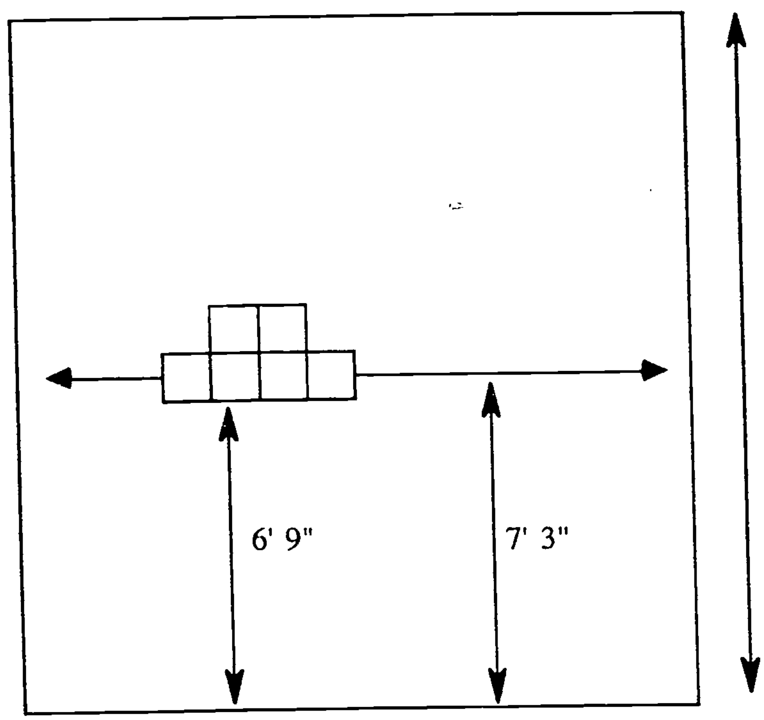

Figure 3

Measuring for a Tile Installation

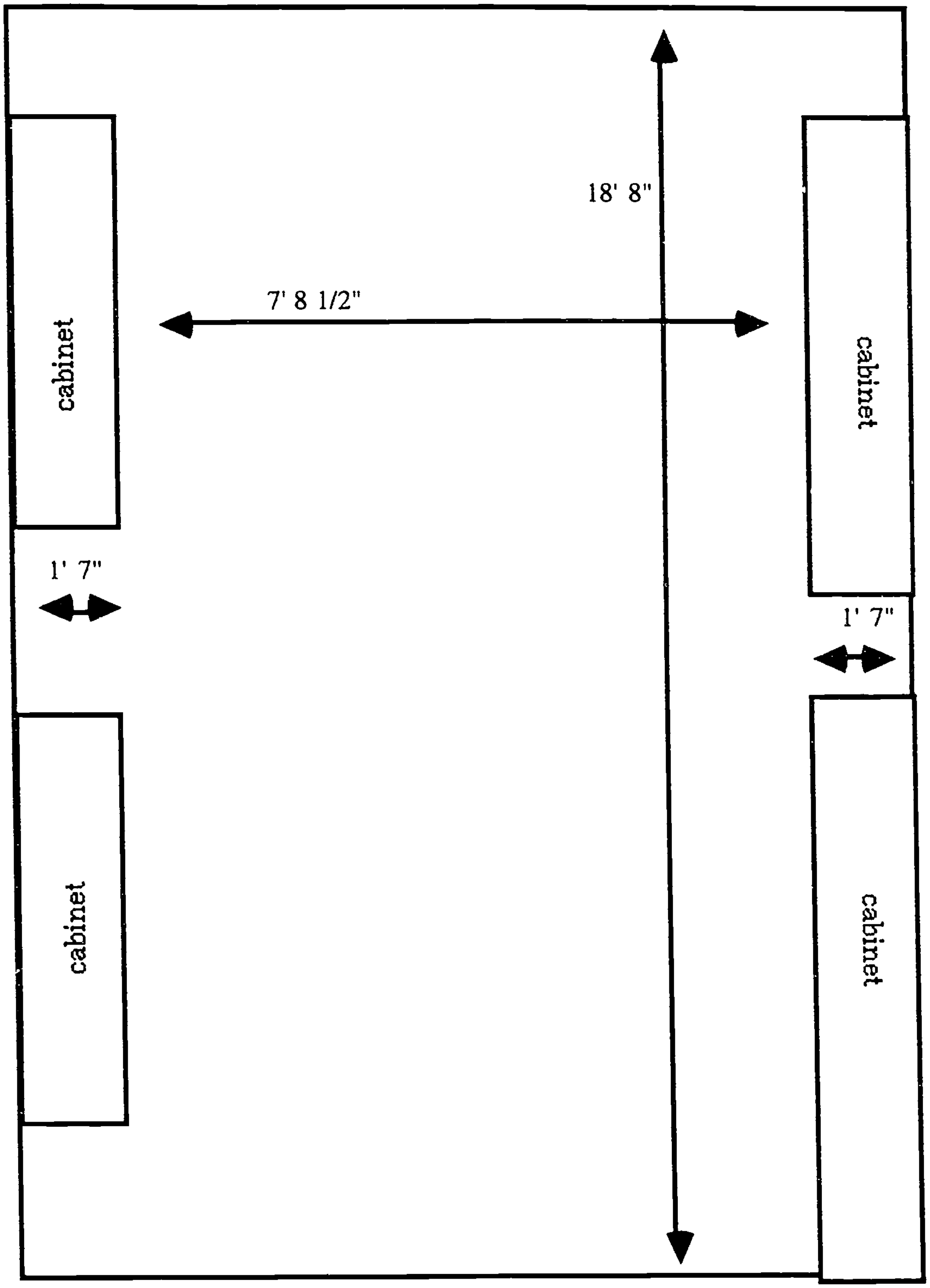

Figure 4